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MECHANICS of Tillage Implements

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ABSTRACT

Tillage operations are especially consumptive of energy. The consumption of energy as well as the wear and tear of tractors and implements increase sharply with working depth. The traditional and still widely practiced tillage system is based on a series of primary cultivations, aimed at breaking the soil mass into a loose system of clods of mixed sizes, followed by secondary cultivation aimed at pulverization, repacking and smoothening of the soil surface. These practices which are performed uniformly over the entire field often involve a whole series of successive operations each of which is necessary to correct or supplement the previous operation, all at the cost of energy and water usage in the case of paddy fields. Existing information on tillage of wet soils reveals that equipment and timing of operations vary with location, soil type and availability of irrigation water and power. Water usage and energy requirements are high due to the increased number of operations. Whilst much work has been documented on the agronomy, breeding, insect and disease control of rice, there is limited research recorded on optimum water levels and the most efficient implement which creates the disturbance required. Although well prepared mud is favourable, experiments to establish the optimum moisture content to obtain such a condition are lacking. This lack of a quantitative description of the degree of puddling poses a major hindrance in performance evaluation of puddling equipment and this in turn hampers the improvement of implement design. The difficulty in quantifying the degree of change in the structure of soil brought about by wetland tillage best suited to the requirement of the rice plant, stems from the fact that very little work has been done to relate the optimum condition to the maximum yield or growth obtained.

This paper focuses on the basic tillage implement requirements for wet soil conditions for both upland and lowland cropping systems based on soil behaviour at higher moisture content. Basic cultivation operations and the types of soil disturbance needed for each are identified. Soil and implement factors influencing draught and power requirements are considered and the action and type of soil disturbance caused by the different implement types are described. A method for choosing the basic implement types necessary for specific field situations is suggested and appropriate tools and techniques are recommended. Implement designs and energy requirements for dry soil conditions are discussed for comparison. Estimation of energy requirements using predictive models based on the Mohr-Coulomb soil mechanics theory is also presented.

INTRODUCTION

Tillage can be defined as any mechanical manipulation of soil. Many different types of tillage tools are available to manipulate the soil. A tillage system is the sequence of tillage operations performed in producing a crop. For many tillage systems, the specific operations can be separated into primary and secondary tillage. Primary tillage is usually the deepest operation to loosen and fracture the soil, to reduce soil strength and mix residues and fertilizers into the tilled layer. The implements used include mouldboard, chisel and disc plough, subsoilers and heavy duty powered rotary tillers. Secondary tillage is used to kill weeds, cut and cover crop residues, incorporate herbicides and prepare a well pulverized seedbed with light and medium weight discs, field cultivators, rotary tillers, ridge or bed forming implements and various combinations of these. They usually operate at depths of less than 12 cm. (Buckingham, 2007). Historically the earliest plough used to till the soil was a wooden plough pulled either by human or animal power. Early evidence indicates that simple lightweight wooden ploughs were employed extensively in the valleys of the Euphrates and Nile Rivers by the year 3000 BC followed by the iron plough fabricated in Northern Honan, China (McKyes,1985). As farmers learnt to work with steel, mouldboard ploughs were developed in the early 18th century. The mouldboard plough was a major development, since it turned the soil and provided for weed control and soil aeration. The principal design features of this implement remain virtually unchanged till today.

Presently mechanical cultivation of wet paddy presents a difficult problem in developing countries where mechanization has not been successfully practiced. In countries where power resources were limited, the power for farming operations was primarily human labour. Later animals such as horses, water buffaloes, oxen, camels and even elephants were used as power sources as shown in Figure 1. Animal drawn implements often consist of comb harrows or wooden or metal drums with lugs or blades.

Figure 1 Land preparation with oxen as the primemover

Mechanical power became the primary source with the development of steam engines in 1858. The first tractor with an internal combustion engine was built in 1889. The tractor's internal combustion engines were lighter and more powerful. In the 1930s the high compression diesel engine was adopted for the tractor and became very popular. Today's modern tractor is a very sophisticated machine with hydrostatic drive, electrohydraulic servo control for draught depth, with ergonomically designed climate control operators (Srivastava et al., 1993). With such mechanical resources in abundance, the land is usually cultivated dry and sowing may be carried out either by drilling in slightly moist soil, followed by irrigation or by broadcasting over already flooded areas. A rubber tyred tractor may be used whilst tractor drawn puddlers may include a steel drum with blades, tine tillers, disc harrows or power rotary tillers aided by cagewheels as shown in Figure 2. Cagewheel extensions have proved advantageous in assisting with the puddling, improving traction and pressing down organic matter. Nevertheless, despite the number and types of implement currently available in the market, no standard implement has so far been recommended for creating the desired puddle layer although the rotary cultivator, disc harrow, rotary puddler and tine tiller have found increasing favour. The capacity of this equipment is low and the draught of the conventional disc harrow is high (Dutt et al., 1986).

Figure 2 Land leveling by a tractor attached with cage wheels

In Asia and South East Asia, the evolution of hardware technology in agriculture, such as farm tools and simple farm machinery, and also the software technology of farming systems has been a very slow process. As advanced countries moved quickly into modern agricultural production and industrialization, few countries were able to follow and adopt modern technology in agriculture notably Thailand, Malaysia and the Philippines (Rijk, 1985).

This created a drastic social change such as the rapid migration of young agricultural workers to cities to engage in industrial work leaving older farmers to manage the farms in the rural areas. More agricultural technology and more farm machines were introduced to take care of the shortage of man-power on the farms. In Laos most of the farming operations are carried out by using traditional farming tools and machineries. Land preparation for seeding or transplanting is done by wooden plough with steel parts. The plough is pulled by buffaloes and one or two labourers control the animals during ploughing. In certain areas power tillers are quite common while the 4-wheel tractor is quite limited in usage. The traditional tools used for farming operations are not designed properly on a scientific basis and are manufactured by local blacksmiths.

TILLAGE AND ENERGY CONSUMPTION

Mechanical manipulation of soil requires energy inputs from fossil fuels. The fuel consumption of a tractor is governed by the amount of energy demanded at the drawbar or through the power take-off. Vilde et al. (2001) evaluated the possibilities and efficiency of soil tillage minimization. They concluded that soil tillage is one of the most power-consuming and expensive processes in agricultural production. They reported that tillage requires 180-320 kWh/ha, which corresponds to 50-80 kg of fuel per hectare of land tilled which makes up 20-25% of the total consumption in agriculture. In Malaysia agriculture is an extremely important business that has expanded into one of the major contributors to the economy. Actions are being taken by the government and various private agencies to modernize this sector. Based on the earlier studies on energy consumption in agriculture (Table 1), land preparation tends to be dominant, besides harvesting (Bardaie et al.,1988). In land preparation the drawbar pull of a tractor consumes a significant amount of total energy input into the tractor implement system. With escalating fuel prices, researchers must therefore be prepared to make the best use of available energy supplies

Table 1 Energy consumption in Agriculture

Land Preparation	Fuel, labour, fertiliser	1980 x 10^6 cal.
Nursery operations	Labour, fertiliser	185 x 10^6 cal
Field transplanting	labour	33 x 10^6 cal.
Crop upkeep and maintenance	Labour, fertiliser	750 x 10^6 cal.
Harvesting	Labour, fuel	1930 x 10^6 cal.
Energy equivalent: (Zohadie et al., 1988)		
Labour/manhours		0.5 x 10^6 cal.
Diesel/litre		78 x 10^6 cal.

Nature of Soil Disturbance

During tillage, forces applied by the implement make clods or aggregates slide over each other into new positions. According to Kurtay and Reece (1970), there are three types of disturbance namely loosening or brittle disturbance, compacting or compressive disturbance and critical state disturbance, depending on soil condition, implement type and force. In loosening or brittle disturbance the soil slides along a few well defined planes and soil density declines. Compacting or compressive disturbance causes particles to move along many planes and soil density increases while critical state disturbance does not cause any change in soil density. Loosening often becomes more difficult as soil becomes wetter or looser while compression is slightly less at saturation. Implement shape determines soil movement and the type of soil disturbance is determined by the shape of the implement.

Tillage implements can be categorized into wide, narrow and very narrow tines. Wide tines are those having a working width greater than the working depth like leveling blades, wide chisel tines, ploughs, angled disc harrows and subsurface sweeps. Narrow tines are those having working width less than the working depth such as cultivating tines and narrow chisel tines whilst very narrow tines are those having working depth much greater than the working width like harrow tines and the mole ploughs. In addition there are three more groups of implements which cover sideways angled blades like disc ploughs and disc harrows, rollers and presses and the powered tines such as the rotary cultivators.

Spoor and Godwin (1978) noted that although the implements are separated into three general groups, the disturbance caused by a given tined implement could fall into any category depending on soil conditions. As tine working depth increases in a given soil the nature of the soil disturbance changes from that of wide to narrow and then to very narrow tine disturbance. The transition from narrow to very narrow tine disturbance at the critical depth is important. As the tine moves below critical depth, soil disturbance at and below the critical depth changes from brittle to compressive. Critical depth increases with increasing tine width (Smith et al.,1989), decreasing tine inclination (Payne and Tanner, 1959) and decreasing soil moisture content. Loose, weak surface soil over stronger, denser soil at working depth tends to increase critical depth. Conversely, strong compact soil above weaker looser soil at working depth reduces loosening at depth.

Soil Forces

Horizontal or draught force can be defined as the amount of force required to pull or push the implement through the soil. Draught forces can be minimized by using the smallest possible tine inclination for the appropriate soil disturbance. Tines with low inclination should be selected for soils with penetration problems. Large inclination is needed when penetration is unnecessary or when heavy downward loads are required to break clods or to smear or puddle the soil. Draught force increases with tine width (Payne, 1956), rake angle (Payne and Tanner, 1959), depth (Godwin and Spoor, 1977) and speed (Stafford, 1979).

TILLAGE ENERGY REDUCTION

Combined Operations

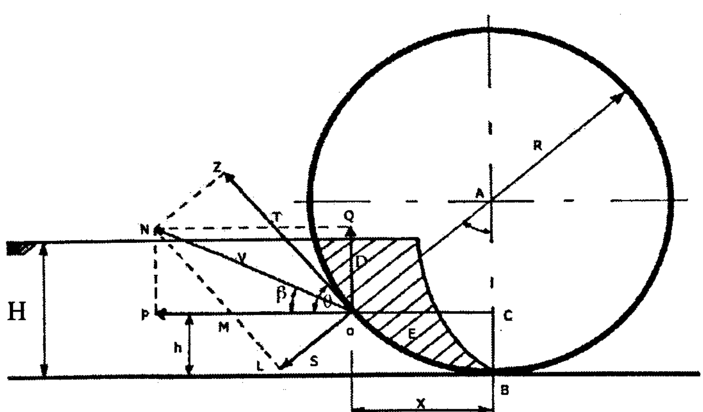
In soil tillage, good seedbed and weed control are two of the problems emphasized. For seedbed, it is generally accepted that an aggregate size range of 5 to 10 mm is required (Russell, 1973). However it is still difficult to recommend what tillage operations are necessary to convert soil in a given condition into a seedbed as the soil structure produced by any given tillage implement depends on a number of factors such as the history of cropping, moisture content and the number of passes of tillage implement. Traditionally the seedbed preparation involves a chain of field operations from ploughing, harrowing, disking, soil packing and so on which eventually cause severe soil compaction and energy usage.

Considerable work has been done in the past to develop suitable tillage combinations for growing crops. This interest grew out of the concern for soil structural deterioration, high tillage costs, delayed seeding and yield reductions as a result of excessive tillage (Godwin et al., 1984; and Gilbertson, 1979). Godwin et al.,(1984) reported that the uniformity of soil disturbance with multiple tine implements depends on tine spacing. With narrow tines working above critical depth under upland conditions, tine spacing of less than 1.5 times working depth is necessary for complete soil breakout at depth. Wider spacing causes incomplete breakout and uneven soil surface. The energy required to cause soil disturbance using combined tine implements is given in Table 2.

Table 2 Energy expended based on chisel spacing and position

Position (cm)	Chisel spacing (cm)	Total draft (kN)	Subsoiler (kN)	Chisel (kN)	Soil disturbance (m^2)	Spec. Res. (kN/m2)
-	-	23.94	23.94	-	0.242	99
16	50	21.41	16.18	5.23	0.238	90
24	50	20.86	12.25	8.61	0.283	74
16	100	21.80	15.23	5.57	0.360	58
24	100	23.48	14.84	8.64	0.418	56

Work on combining the rotary cultivator with tines was reported by NIAE (1970). All tests were conducted with tines set deeper than the rotovator depth. With the tines following the rotovator less draught was encountered since the tines worked in loose soil. However when the tines were in front, there was a considerable increase in draught due to the tines working in undisturbed soil. Although the rotor power would decrease, the total power requirement increased significantly. In contrast to the work reported by NIAE, Gilbertson (1979) conducted a study on combined operations using shallow leading winged tines. He concluded that with the winged tines operating at shallower depth the total power requirement was not significantly greater than the power when the rotovator was operating alone. With the tines operating at similar depth as the rotovator, a significant increase in total power was observed compared to when the rotovator was operating alone. The existence of an optimum tine depth ahead of the rotovator whereby the power consumption would be less as a result of the maximum thrust exerted by the rotovator was suggested (Figure 3). The hypothesis postulated was later verified by Desa Ahmad (1983). The apparatus used consisted of a test rig with a rotary cultivator combined with winged tines complete with instrumentation for recording the force, speed and power required. An extended octagonal ring transducer was used to measure the draught force of the rig whilst the speed and torque of the PTO shaft were measured using a torque meter. In order to assess soil fragmentation, several photographs of the clod distribution were taken using a grid of standard dimension. The grid was first laid onto the soil surface and a photograph taken from a standard height with the line of sight perpendicular to the surface of the grid. Results of the experimental work reveal that in the absence of winged tines, the rotovator power requirement was very high. Prior loosening of soil by winged tines at shallower depth showed no significant change in total power requirement. Considerable reduction in rotovator power was observed when the winged tines were set to about 85% of the rotovator depth whereby there was a 20% reduction in total power requirement as compared to when the rotovator was operating alone. Additionally it helped reduce the number of machine passes in the field and hence reduce soil compaction which is detrimental to root growth. Shallow leading winged tines ahead of the rotovator caused the most soil fragmentation in lateral distribution of clods compared to the rotovator operating alone. The use of shallow leading tines ahead of the rotor also proved to be advantageous in terms of total power requirement compared to the power required to perform the operations separately. Overall power consumption increased when shallow leading tines were set to work at rotor depth though a reduction in rotor power was observed.



M = Horizontal thrust (OP)
D = Vertical thrust (OQ)
T = Tangential force
S= Radial force
V = Resultant force

H = Working depth
θ = Rotational angle
h = Height of point of max thrust
X = Distance of O from rotor centre
O= Point of action

Figure 3 Theory of maximum thrust

Water Reduction Technique

The traditional and still widely practiced tillage system is based on a series of primary cultivations, aimed at breaking the soil mass into a loose system of clods of mixed sizes, followed by secondary cultivation aimed at pulverization, repacking and smoothening of the soil surface. These practices performed uniformly over the entire field often involve a whole series of successive operations each of which is necessary to correct or supplement the previous operation all at the cost of energy and water usage. Under flooded conditions, puddling is done using the traditional plough which merely disturbs the soil whilst soil churning, mixing, inversion and compaction are made effective by animal or human trampling. In mechanized fields puddling requires inputs of mechanical energy and for resource poor farmers, the cost of these energy inputs should be minimized. Efficient use of water at this stage will result in the ability to supply additional areas with the same amount of irrigation water, thus increasing the productive irrigated area. Generally land soaking and land preparation (ploughing and puddling) use one third of the total water supply in growing rice crops (De datta, 1981). Based on the IRRI Report (2008), worldwide, 80% of developed water supplies go to irrigation, and in Asia more than half of that is used to grow rice. The water usage is often in excess to help in scouring apart from reducing soil strength. With increasing demands being made on water resources worldwide for industrial and domestic use, the water available for agriculture is likely to become more scarce and more costly. There is a need to improve the efficiency of water use by crops and to avoid wasteful applications of irrigation water.

Maximising the use of irrigation water requires strict control of soil water usage, particularly during field preparation. Another possibility is to utilize rain water for land soaking saving the irrigation water for crop growth. Sarker (1985) showed that pre-irrigation tillage (tilling of the field well before inundation and usually relying on residual moisture content) reduces water requirements significantly compared to post irrigation tilling (tilling after irrigation water is supplied). Pre-irrigation tillage produces loose clods that are easy to break up and churn into mud when soaked with water. Earlier work by Koenigs (1961) showed that preparing mud from dry clods is much easier and uses less water than preparation from undisturbed soil. In order to benefit from these findings, clods formed in pre-irrigation tillage of rice soils should be able to absorb water quickly. This is important especially in areas where water is scarce and the time to prepare the land is short. Desa Ahmad (1996 and 1997) studied the rate of water uptake by clods of different sizes and initial moisture content using the capillarity method and found that the rate of water absorption was greatest when clods were initially very dry. Continuity of flow was better when the clods were confined. Imposing loads helped to reduce swelling and hence reduced crack formation. On wetting water moved into the clods under the action of potential gradient. The moisture tension in the clods decreased as the clods swelled. This swelling process continued until the potential gradient was reduced to zero. Under confined conditions, further swelling was restricted resulting in the building up of pressures within the clod. This reduced the moisture tension and the potential gradient. Equilibrium was established when the potential gradient became zero. These phenomenons were also reported by past researchers (Yong and Warkentin, 1978; Spoor et al., 1985; and Stengel, 1988). Smaller clods were found to absorb water faster than larger clods for a given initial moisture content when in a confined state. When clods were unconfined, the rate of water absorption tended to be greater with larger clods than the smaller ones as time progressed, due to formation of cracks in the smaller clods. These cracks were absent in the large clods because of the slow upward movement of water during the specified wetting period which delayed the swelling effect. The effect of confining was to improve water absorption when the clods were initially very dry. Confining had no effect on water absorption when the clods were initially very wet.

In the paddy field, various forms of soil manipulation are required to change and improve soil conditions. This may involve breaking up any clods present, increasing moisture content to reduce clod strength, forming puddles, mixing organic material, soil smearing and compacting at depth. These conditions may have to be achieved under circumstances where either water or power resources (or both) are limited. As wet clods are weak in strength and easily broken, it is vital to have clods that can absorb water in the shortest possible time, especially in areas where water is scarce or the time for land preparation is short. The fact that smaller clods absorb water faster than larger clods indicate that they are more energy efficient in soil puddling than larger clods since the process of wetting and weakening in strength is more rapid. The studies have also shown that rapid water absorption is more evident with dry clods than with wet ones. At lower initial moisture content, clods are much stronger and benefit from wetting if energy to break the clods is limited. When clods are more densely packed (confined state), water absorption is more rapid. Based on these findings, consolidation of surface clods could ensure rapid wetting and weakening of clods in conditions of wetting by capillarity.

The effect of water quantity on the degree of puddling using air dried aggregates was also studied (Desa Ahmad, 1993). The work was confined to a laboratory study since it would be difficult to control water levels in the field. The property of the puddle soil in terms of wet bulk density and aggregate size distribution was determined and compared with the optimum conditions for rice root growth as found in literature. Puddling was done using a rotary puddler to simulate the rotary motion of the rotary cultivator normally used in the field at different water-soil ratios. The puddler was driven by an electric motor with a variable speed controller. The rotary cultivator is a good implement as it disperses soil particles quickly and requires negative draught force. For a given energy input, aggregate breakdown could be increased and soil wet bulk density decreased by increasing the amount of water to a certain limit, beyond which there would be little further change. Water quantities above this limit would be wasted from puddling point of view. For a given water-soil ratio, increasing the energy input would increase the aggregate breakdown and reduce the soil wet bulk density values. The reduction in soil wet bulk density with stirring time was due to the slower settling rate of the fine particles remaining in suspension. These aggregates would have settled with time increasing the wet bulk density.

In the field situation the amount of water required would depend on the initial state of the soil and the type of soil used. When dry soil is suddenly and thoroughly flooded its aggregates become saturated with water and its cohesion decreases. The individual aggregates become soft and may or may not disintegrate depending upon their stabilities. Where energy is limited but water is readily available, increasing the supply of water would be beneficial, but there would be little gain from using excess water. On the other hand, where energy is in abundance, the use of water could be reduced. Hence in soil puddling, there ought to be a balance between energy requirement and minimum water use.

Formation of Clods

In dryland cultivation soil clods are normally formed during secondary tillage. Secondary tillage works the soil to shallower depth, provides additional pulverization, levels and firms the soil, kills weeds and help conserve moisture. The implements used for secondary tillage are normally the disc harrow, tine cultivator and rotary tiller. The disc harrow and tine cultivator are ineffective in producing clods in a single pass whilst the rotary tiller consumes more power. The size of the blade bite is determined by tractor forward speed, number of blades per flange and rotor speed. Larger blade bites cause less soil pulverization and reduced power requirements. Lowest rotor speed and largest blade bite are normally recommended for an acceptable tilth or degree of pulverization. Tilth also depends on the shield adjustment. Raising or lowering the soil shield controls the amount of soil shattered as clods leave the rotor. For fine tilth, the soil shield is normally lowered and a fast rotor speed or slower tractor speed is selected. For coarse tilth, the soil shield is raised whilst the rotor speed is lowered or the tractor speed increased. L and C- shaped blades are available but the L-shaped blade is the most common as it is better for killing weeds and causes less soil pulverization compared to C-shaped blade which is more suitable for wet soil as it has less tendency to clog the rotor. The L-shaped blade however, consumes more power. Attempts were made (Desa Ahmad, 1986) to reduce the power requirement of the L-shaped blade by changing the size of cut of a rotary blade and studying its effect on the resultant clod size. Using aggregate size of about 10 mm as reference, the results clearly illustrate a trend towards using narrower cutting widths for finer degree of soil pulverization. In terms of energy requirement, the lowest energy requirement was achieved at 50 mm width. The energy required was higher for widths below 50 mm and above this value. The increase in width, however, was not compatible with the degree of soil breakdown required and gave a comparatively poorer percentage of aggregates formed.

In addition to producing clods from dry soil, the formation of clods from wet clay soil was also investigated (Godwin et al., 1989). Soil fracture under plastic conditions was determined using a modified triaxial apparatus as shown in Figure 4. Samples were subjected to different kinds of loading such as torsion, tension, bending, direct shear and direct cutting. Results obtained suggest that placing wet plastic clay soils into bending is an effective method of causing soil fracture with minimum force (Figure 5).

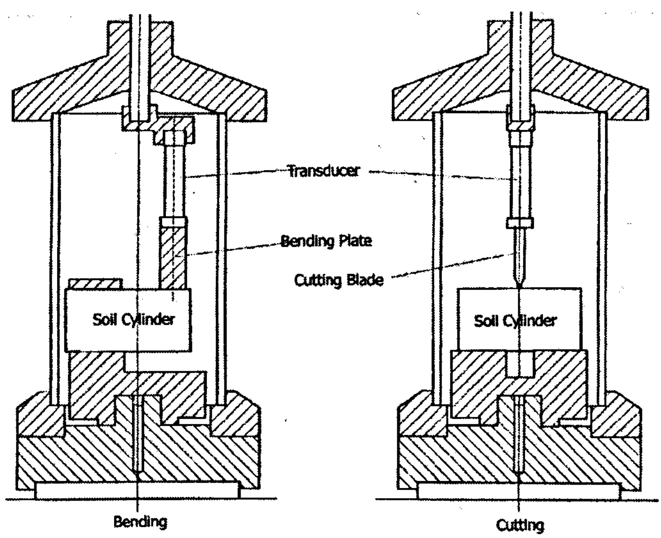
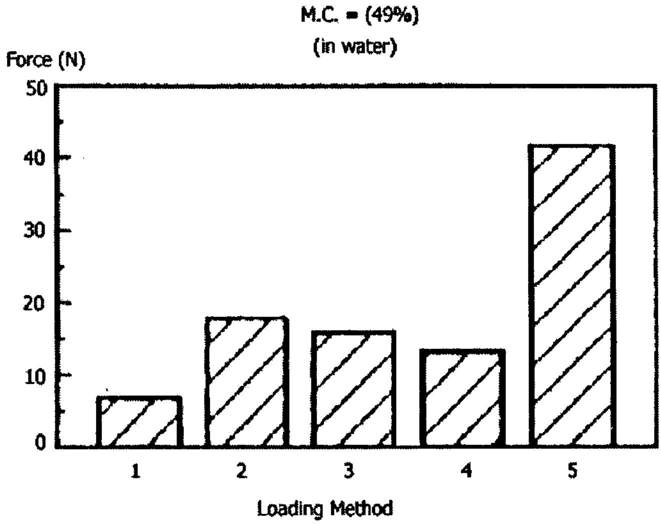


Figure 4 Bending and cutting wet soil samples.



1. Bending 2. Cutting 3. Relieved Cutting 4. Direct Shear 5. Tension

Figure 5 Effect of loading methods on soil fracture force.

In practice this is best achieved by using a rotating cutting blade and a reaction plate about which bending is induced. The relative position between the reaction plate and rotating blade is an important parameter affecting performance. By the direct positioning of the reaction plate and rotating blade, the tangential force and energy requirement can be reduced to approximately 50 - 65% and 20% respectively of that required by the rotary cutting techniques widely used in the tillage of paddy fields (Figure 6).

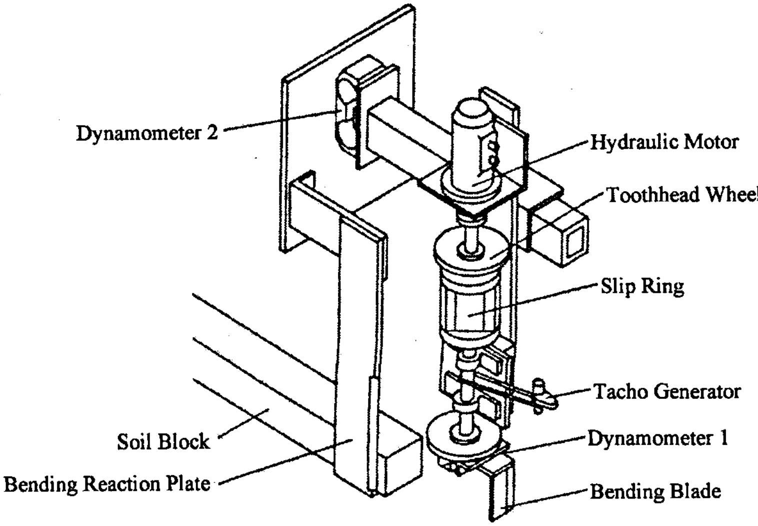
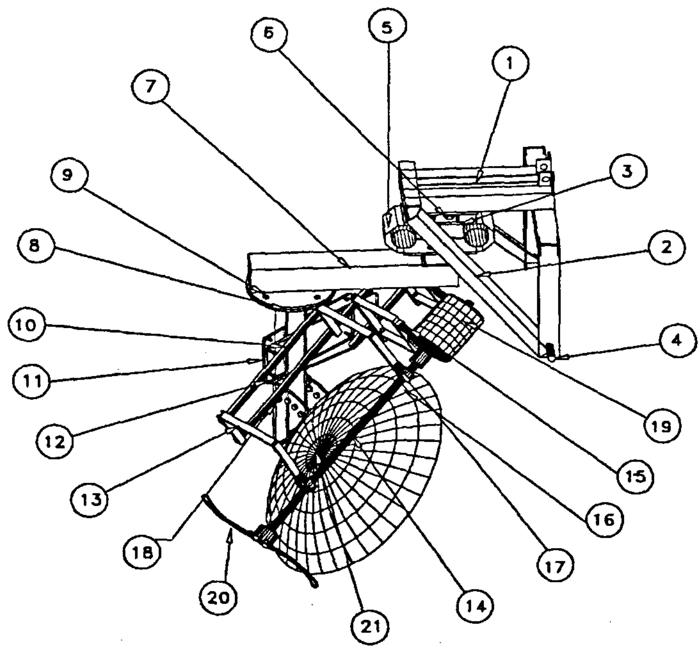


Figure 6 Experimental rotary cutting technique

Based on the findings a new tillage implement consisting of a disc plough and a rotary blade was designed and fabricated using a single frame for both operations so as to reduce traveling of the machine in paddy fields (Faizal et al., 1999). Tests were conducted in a soil tank 20 m long, 3 wide and 0.75 m deep with Munchong series and soil condition was controlled. A 25 HP tractor was modified and used as the prime mover (Figure 7).

Figure 7 Soil tank and gantry system

An extended octagonal ring dynamometer was used to measure the draught force and a torque transducer for measuring the torque (Figure 8). Based on the existing information on disc plough-soil parameters, the effects of forward speed, disk angle, tilt angle and width of cut were explored. Results between soil-disc parameters design were compared and the flow of soil slice on disc surface was determined. Tilt angle had no effect on draught while the forward speed showed significant effect on force and energy requirements (Figure 9). Studies on soil flow on disk surface showed an upward flow which increased as the forward speed increased. Increasing disc and tilt angle would increase soil flow on the disc surface. The use of a rotary blade with reversed rotation was an effective method to reduce energy requirements.



All dimensions are in mm

1. Sub Frame 1 (U-Shape 75x50)
2. Sub Frame 1 (Angle L 75x50)
3. Sub Frame 1 (Plate 10)
4. Sub Frame 1 (Solid dia.25)
5. Dynamometer (150x150x400)
6. Bolt
7. Sub Frame 2 (Sq.-Shape 100x100)
8. Sub Frame 2-3 (Plate 10)
9. Bolt & nut
10. Sub Frame 3 (U-shape 125x60)
11. Sub Frame 3-4 (Plate 10)
12. Bolt & Nut
13. Sub Frame 4 (U-shape 50x25)
14. Sub Frame 4 (Solid dia.25)
15. Bolt & Nut
16. Pillow Block (dia.25)
17. Bolt & Nut
18. Bolt & Nut
19. Torquementer
20. Blade and Base (225x5xR125)
21. Disc and Bearing (dia.600)

Figure 8 Location of dynamometer and torque meter on the experimental frame

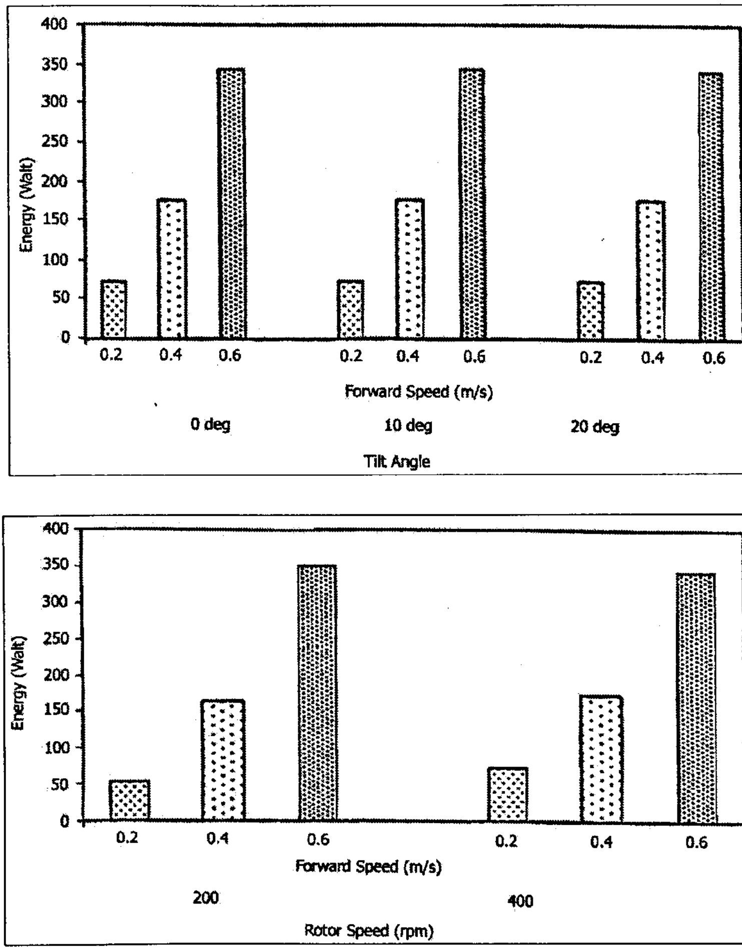


Figure 9 Relation of tilt angle and rotor speed to energy requirements at different forward speeds.

TRACTOR POWER AND DRAUGHT CAPABILITY FOR TILLAGE

Tractor power is utilized in two ways by transmitting the engine power both through the driving wheels as traction to provide the drawbar power required for draught implements, and through the power take-off shaft as well as the hydraulic system to provide mobile support for attached machines. Tractor engine torque is converted into tractive thrust at the ground drive wheels by pushing against the soil in contact with the lugs of the tyres. The weaker the soil, the lower the tractive thrust available. Not only is there less traction, but there is also more resistance to the forward movement of the wheel as it sinks more deeply into soft ground (ElWaleed et. al., 2006). This restricts the net force or pull which can be effectively utilized both to propel the tractor and also to pull draught implements at the tractor drawbar. Figure 10 shows the effect of the vertical loading of the tyre on drawbar pull available from a wheel (Whitney, 1988). As the weight on the tyre increases, there is a linear increase in gross tractive thrust. The rolling resistance which is minimal for low vertical loads on the tyre progressively becomes more substantial until it finally exceeds the tractive thrust. At this point, the tractor, even without any towed equipment, becomes immobilized.

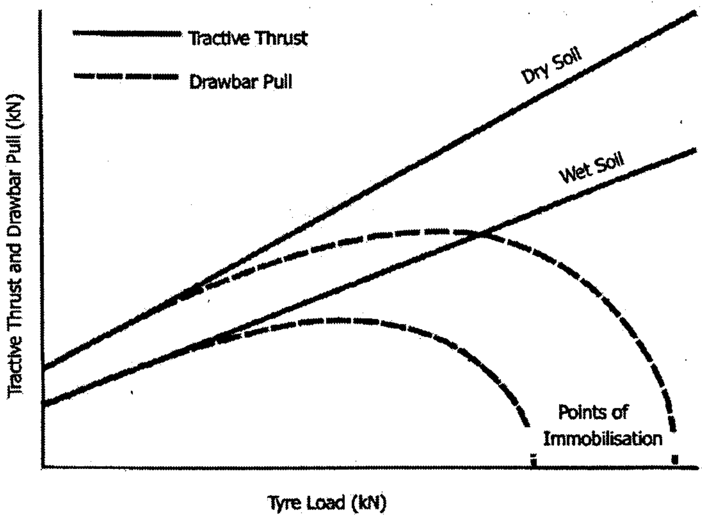


Figure 10 Relation of tyre load to tractive thrust and drawbar pull (Source: Whitney, 1988)

Tractive performance is essential for heavy draught operations, such as ploughing and this drawbar dictates the total power requirement. On dry upland soil conditions, tractors can pull about half their weight. In rice fields where tractors obtain support and traction from the pan at the base of the puddled zone, the pull may be less. Dry land soils are frictional-cohesive soils, whereas in wetland they are more likely purely cohesive. In dry land each increment of weight added increases the thrust of the tyre while in wetland, because of no effect on thrust, the rolling resistance increases (Gee-Clough et al, 1978). Hence the vehicles for wetland operations should be as light as possible. This is because the pan's support capacity limits tractor weight and pressure and therefore traction. Additionally the pan may be destroyed by excessive tractor wheel slip or by drivewheel penetration thereby causing serious problems. Moreover powered implements that develop a forward thrust do help overcome traction problems. Where the minimum draught requirement exceeds available draught or tractive force, tillage can sometimes be implemented in stages where each has sufficiently low draught requirements. Implements that can work progressively deeper at each pass can be useful. In lowland rice fields, traction problems have been a major limitation to the adoption of mechanization in rice producing Asian countries (Tanaka, 1984). Deep sinkage and high wheel slip involved lead to inefficient use of power or incomplete farm operations (Gee-Clough, 1985). Substantial thrust can only be achieved by using the strength of the base pan or compacted zone. Implements such as seeders, planters and fertilizer applicators are frequently ground driven, and therefore the drivewheels must develop a thrust force at constant working speed. This can be achieved by using a wheel with spikes that extend through the puddled soil into the underlying compact layer. When very little forward thrust is needed, paddle wheels working in the puddled layer may be adequate. Under flooded conditions, the maximum tractive efficiency for cage wheels is much better than the tyre wheels.

Tracked vehicles have long been recognized to give better tractive performances and cause less soil compaction than wheeled vehicles. Steel tracked vehicles have not been widely used in agriculture simply because they are slow, heavy, expensive and have high rates of wear in abrasive soils. However, recent availability of new steel reinforcement and rubber moulding techniques have made it possible to construct rubber tracks of adequate strength and durability for use in agricultural vehicles (Figure 11).These newly developed rubber tracks are cheaper and lighter than steel tracks and allow the vehicles to operate on public roads at the same speed as tractors. Modifications of tyre design have shown little potential for significant tractive improvements while rubber tracks have proved to have great potential.

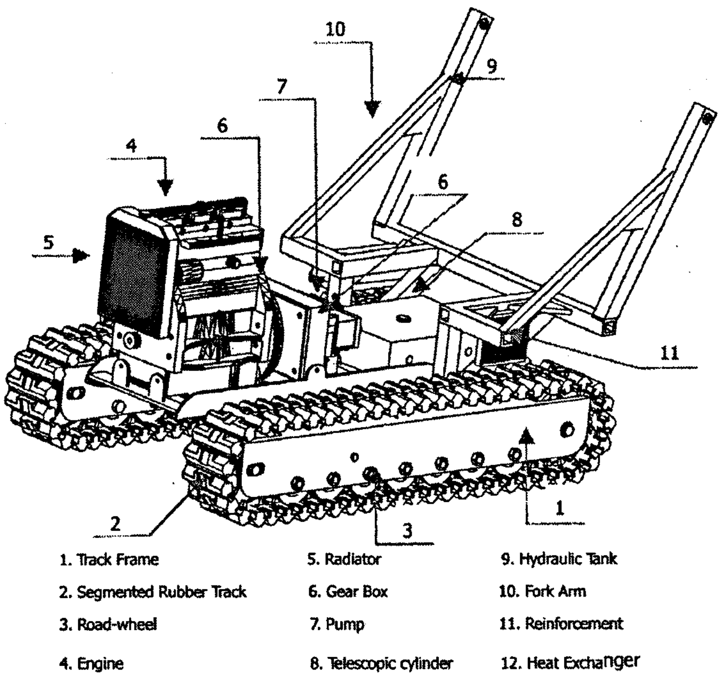


Figure 11 Segmented rubber tracks

(Source: Ataur *et al.,* 2005)

Tractive performance test on rubber tracked vehicles has claimed that they develop more drawbar pull, higher tractive efficiency and higher dynamic traction ratios with less slip than wheel vehicles on pneumatic tyres. However rolling resistance of the tracks is higher than that of the tyres which resulted in the magnitudes of maximum tractive efficiencies being similar for both vehicles. On the other hand because of the better pull-slip relationships for the tracked vehicles, the magnitudes of pull and coefficient of traction at maximum tractive efficiency are much higher than the wheeled vehicle. Tractive performance differences between rubber tracked and wheeled vehicles are claimed to be more pronounced in softer terrain surfaces. This means that rubber tracked vehicles could give the same rate of work at the same speed and operate a wider range of implements efficiently without addition of ballast compared to wheeled vehicles. Furthermore the flexibility offered by the segmented rubber tracks could result in less repair and maintenance costs (Ataur *et al.,* 2005; 2006a and 2006b)

CONSTRAINTS TO IMPROVING SOIL PREPARATION

Presently considerable progress has been made in designing low energy implements for dryland cultivation. For wetland cultivation, however, little is known. The pressing need for design information to supplement the current qualitative procedures has demanded that methods for design be developed. Basic tools such as the traditional wooden plough date back into antiquity, yet, they are still found in their original form in many parts of the rice growing countries. Even in more advanced countries, the mouldboard plough is designed by empirical methods. The tool is varied in some manner and acceptable designs are identified when the resulting soil condition is adjudged to be satisfactory. Quantitative descriptions or representations of the final soil condition are seldom used and, in addition, the forces required to move the tool are frequently not quantitatively assessed.

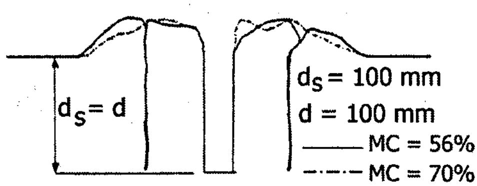
Over the years, there has been very little improvement in the animal drawn implements used for rice cultivation. The local wooden plough and plank seem to be the only implements used for most puddling and leveling activities. The introduction of tractor power has often not affected the type of implement used. Spoor et al, 1985 stated that for efficient equipment design and selection, it is vital to have knowledge of necessary soil conditions and of the transformation needed to achieve them. Implements selected or desired must produce the required results under prevailing soil and moisture conditions and utilize minimum power and draught. In the light of the difficulty in developing new implements for wetland cultivation, advances could be made by resorting to fundamental studies under the prevailing soil and moisture conditions. According to Gill and Vanden Berg (1968), the key to the development of a scientific approach to tillage is the establishment of a soil-implement mechanics base capable of describing and predicting the action of a tillage tool on the soil. Once a realistic soil-implement mechanics base is developed, it can serve to predict soil behaviour and help in the selection of appropriate tillage tools and in the improvement of tillage efficiency. For wetland tillage research, it is vital to conduct an investigation on the reaction of wet soil to external forces imposed by agricultural implements and the energy input required while working in the wetter range. This is important since the choice of implement and the level of moisture content have significant effects on power requirements and the resultant mixture.

DEFORMATION OF SOIL IN DRY AND WET CONDITIONS

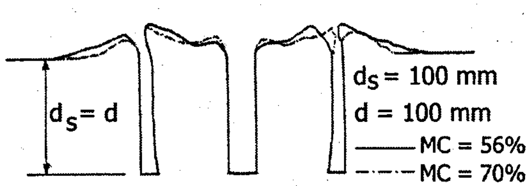
For upland crops tillage provides a seedbed of fine tilth to ensure adequate seed-soil contact, especially when the seed is dry. Deep tillage also breaks up natural or induced restricting layers and stimulates rooting for optimum growth of upland crops. The plastic limit, PL, marks the transition between brittle and plastic consistency. The liquid limit, LL marks the transition between plastic and liquid consistency. In some soils, gravimetric water content near 0.9 PL provides maximum friability. Tillage at this optimum water content maximizes the proportion of small aggregates. Spoor and Godwin (1979) reported that brittle failure and hence clod formation can occur at higher moisture content above the lower plastic limit provided confining stresses are low. The results, however, were observed in a triaxial test and not evaluated in the field or soil tank.

An investigation was later carried out to study the deformation of soil at high moisture content (Desa Ahmad, 1995). Experiments were conducted in the plastic moisture range using simple tines operating at various rake angles and depths in a soil tank. A laboratory study was adopted because of the ease of controlling moisture content and the absence of weather effect as would normally be experienced in the field. The principal objective of the study was to utilize soil-implement mechanics knowledge to improve the efficiency of soil preparation for wetland crops. Aspects like the nature of disturbance, extent of disturbance and draught requirement were investigated. Based on the results obtained, it can be summarized that failure of wet soil was more of a flow type rather than brittle. No clearly defined slip planes were formed. Soil movement was greatest near the tine side decreasing rapidly with distance. Wedges were formed ahead of all tines and these forced soil ahead and sideways depending upon tine rake angles. With forward inclined tine, there was more upward and forward movement giving the lifting effect thereby reducing the sideways movement. Some upward and forward movements were observed with the vertical tine but the sideways movement was much more in evidence. The backward raked tine had the largest sideways movement while greater mass of soil was pushed forward ahead of the tine. The height of lateral heave for the forward raked tine was greater and its lateral extent smaller compared to the vertical tine. The lateral extent of heave for the backward raked tine, was however, more extensive.

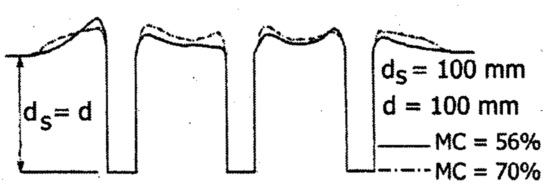
With multiple tines, disturbance was more affected by the spacing of the leading tines. At the narrowest tine spacing, slots were formed initially but as the rear tine moved forward, the two slots were almost closed by the moving mass of soil being pushed by the trailing tine. As spacing increased, the slots remained open. The profile of heave was more uniform at closer spacings than at wider spacings. At wider spacings distinct formation of individual heaves was observed (Figure 12). There was little difference in surface disturbance between the leading tines acting shallower or at the same depth as the rear tine.



(a) Tine lateral spacing = 100 mm



(b) Tine lateral spacing = 150 mm



(c) Tine lateral spacing = 200 mm

Figure 12 Profile of soil disturbed by multiple tines.

The height of soil heave was also affected by tine spacing. As the spacing between interacting tines increased, the height of the heave of the disturbed soil in between the tines decreased. The maximum height of soil heave measured for the homogeneous soil condition was less than half the working depth of the tines when the leading tines were operated at the closest spacing with all tines at the same depth. In the dry field, Willatt and Willis,(1965) obtained a higher soil heave. The reason for this could be due to the heterogeneous soil condition where soil breakdown is normally determined by initial soil state and soil density which vary between surface and subsurface layers. In the drier condition, brittle failure would be prevalent. In very wet condition where compressive failure is more dominant, the height and extent of heave formed would be restricted by the thixotropic properties of the soil which behaves more like a fluid as the saturation level increased towards 100%.

In the context of soil puddling, soil water interaction would be better achieved by positioning the interacting tines at closer spacings since any water trapped in the slot initially created by the leading tines would be compressed into the soil mass. The magnitude of the draught force component would also be less at closer spacings. At wider spacings, soil water interaction to achieve the desired degree of puddle would be less effective since tines would only create vertical slots of the same width as the tine. Water trapped in the slot would not be squeezed completely since sideways movement of soil deformed by the adjacent tines would be limited by their distance apart. Hence more passes would be required incurring higher energy usage.

IMPLEMENT DRAUGHT AND DRAWBAR POWER PREDICTION

The drawbar power requirement is the product of implement draught and operating speed. Whilst the same rate of work can be maintained either by pulling a wide implement at low speed or a narrower implement at a higher speed, the drawbar pull demand varies substantially (Whitney, 1988). Zoz (1972) developed the Tractor Drawbar Performance Predictor nomograph to predict the drawbar pull whilst Terratec (1982) produced the Ploughing Performance Predictor Chart which demonstrates the sensitivity of the power requirements of the various characteristics of a particular plough. A fully instrumented tractor procured by the Department of Biological and Agricultural Engineering has the capability to measure, display and record tractor engine speed, travelled speed, rear wheel speed, power take-off (PTO) speed, fuel flow, rear wheel torque, PTO shaft torque, pitch and roll angles, drawbar pull, tillage depth and three-point hitch forces when the tractor-implement is operating in the field (Kheiralla and Azmi, 2001). The utilization of spatial variability technique in obtaining the tillage energy requirements of disc ploughing operations, first rotary after disking and second rotary tilling after disking using the instrumented tractor was studied by Yahya et al.(2006). Spatial variability of soil terrain characteristics, tractor implement performances and tillage qualities were measured using the mapping system that consists of an instrumented tractor with built-in data acquision system, differential global positioning system and transducers, mounted soil penetrometer - shearometer unit and trailed type soil surface profile digitizer. The collected soil terrain characteristics and tractor implement performance data sets were transferred to the ArcView GIS software to produce spatial interpolated surface maps for further statistical analyses. SAS statistical software was used to perform univariate, correlation and stepwise multiple regression analyses to generate mathematical models for tillage energy requirements. Despite the sophistication of the features built into the tractor, it can only provide in situ measurements which have to be repeated for other soils, implement types and operating conditions. It requires a database for various operating conditions to enable, for instance, a farm manager to decide on the suitable tractor size for a particular ploughing operation on a particular field. This necessitates a fundamental study on tillage power prediction in an effort to optimize the energy requirement.

Optimizing energy requirements in tillage has been one of the major objectives of agricultural research engineers for many decades .Tillage prediction has been found to be a difficult task due to the many input variables considered in the system. Design of field implements is based not only on the machine or implement performance but also on the behaviour of soil and soil-implement interactions. Earlier researchers developed mathematical models to predict the magnitude of the soil forces acting upon implements of different geometry (Godwin and Spoor, 1977, Godwin and Wheeler, 1996 and Wheeler and Godwin, 1996). These are based on the general soil mechanics equation developed by Hettiaratchi et al. (1996) for the wide tines (or blades) and that of Hettiratchi and Reece (1967) for the narrow tines. These equations enable the draught and vertical forces to be calculated from knowledge of the tool geometry, working depth, soil physical properties and the type of soil disturbance pattern produced by the tool. They have been integrated into a unified model described by Godwin and O'Dogherty (2007) and formulated into a number of spreadsheets for the use of those who wish to estimate the effects of different implement geometry on the soil forces in a given soil and the effect of different soils on a given implement shape such as single and multiple tines, land anchors, discs and mouldboard ploughs.

The soil failure patterns modeled in the earlier theories include the actual observed failure surface boundaries and simplified patterns involving both horizontal and vertical deformations. The experimental verification of the above theories has been limited to tests largely on soil of hard and friable consistencies or at the lower end of the plastic range where mainly brittle failure occurred. The exceptions to this are the works of Wismer and Luth (1972) who used dimensional analysis and Stafford (1979) who developed a mathematical model involving the operation of a rigid tine in a cohesive soil at several moisture contents and operating speeds.

Prediction models based on the Mohr Coulomb soil mechanics theory were developed to predict the interaction between soil and simple implements used in the study based on soil disturbance pattern (Desa Ahmad, 1995).The trajectory of the soil particles was monitored by soil movement detectors in the shape of coloured plastic beads implanted in a regular grid in the path of the tine at various depths in the X, Y and Z planes as shown in Figure 13. The movements were measured before and after the passage of each tine. A glass sided tank experiment was also conducted to support the bead tracer technique in observing soil deformation. Three failure mechanisms were identified with tines of different rake angles. The forward inclined tine displaced the soil forward and upwards at all moisture contents within the plastic limit with some soil movement sideways at higher aspect ratios (depth/width). At lower aspect ratio, the type of failure was purely two dimensional. The vertical tine pushed soil upwards, forward and sideways similar to a three dimensional type of failure. No rupture plane was observed. These two tines acted like a retaining wall when it was wide with the result that when soil failure occurred the movement of the soil was in the vertical plane (upwards and forward).When the tine was narrow, the movement of the soil was in the horizontal plane with a soil wedge moving slowly upwards in a column along the face of the tine. The nature of soil failure was predominantly lateral. The second mechanism of soil failure was dependent on the critical aspect ratio. The backward raked tine pushed the soil forward and sideways with a static wedge being formed on the face of the tine.

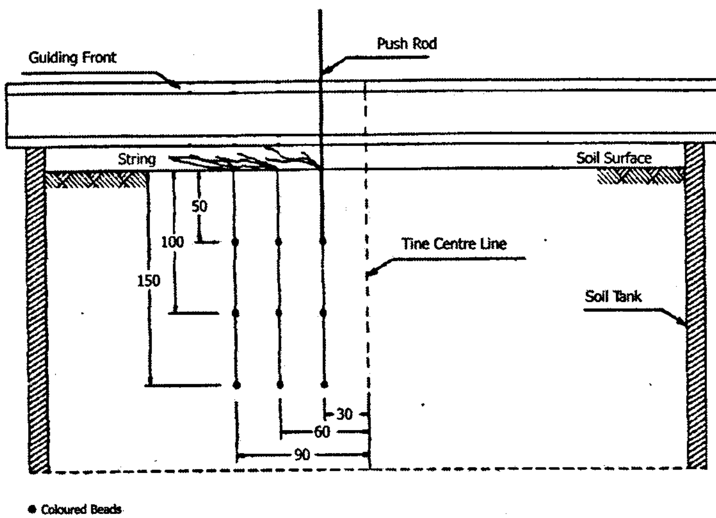


Figure 13 A sectional view of the soil tank

For wider blades (lower aspect ratio) the failure mechanism observed was purely two dimensional where soil nearer to the tine moved mainly upwards and forward. Based on this observation, use of the two dimensional soil failure model developed by Hettiaratchi and Reece (1974) was adopted. Hettiaratchi and Reece (1974), presented a simplified method to calculate the horizontal force, H, as:

$$H = (\gamma d_c^2 N\gamma + cd_c N_c + c_a d_c N_a + qd_c N_q) w \sin(\alpha+\delta) + c_a d_c \cot\alpha$$

where γ is soil dry bulk density, c, the soil cohesion, c_a, the adhesion between the soil and the tine interface, d_c, the critical depth, w, blade width, α, the rake angle, δ, angle of soil-tine shearing resistance and q is the surcharge on the soil surface. The N-factors represent soil resistance coefficients (dimensionless number obtainable from charts).

This prediction model, however, has a limitation in that the forces generated by the moving soil zone sliding along the slot walls are neglected. In cohesive soils, these sliding forces are significant as shown earlier by Zhang and Shao (1984) in their work on the dynamic performance of a single lug in wet clay soil. In predicting the total draught force, therefore, these sliding force components were added to the two dimensional model in addition to the sliding resistance resulting from the forces generated by the soil zones against the furrow walls and the crescent effect manifested in the form of a heave around the tine (Godwin et al., 1985). The total horizontal force for lower aspect ratio is thus given as:

$$H1 = [(\gamma d_c^2 N_\gamma + cd_c N_c + c_a d_c N_a + qd_c N_q)(w + d_c(m-1/3)x\ (m-1)]\sin(\alpha+\delta) + c_a d_c \cot\alpha + mcd_c^2 \sin(\alpha+\delta).$$

With narrow tines having an aspect ratio greater than one, the soil can be considered to fail in a two dimensional manner in a horizontal plane. This type of failure is similar to that of a deep narrow footing as described by Meyerhof (1951) and later adopted by Godwin and Spoor (1977) as a basis for their lateral failure theory for very narrow tine. The characteristic feature geometry for the lateral failure at higher aspect ratios is based on the model expounded by Godwin and Spoor (1977) as shown in Figure 14 but modified to include the side forces resulting from the rising soil wedge.

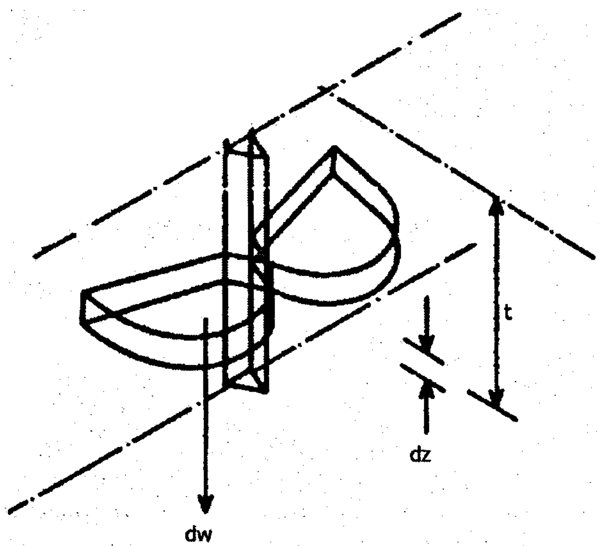


Figure 14 Lateral failure at higher aspect ratios
(Source: Godwin and Spoor, 1977)

The total horizontal force is given by the following equation:

$$Q = w\,[cNc'(d-d_c) + 0.5\gamma K_o Nq'(d-d_c)^2]\sin(\alpha+\delta) + wc(d-d_c)$$

where d is the total operating depth, K_o the ratio of horizontal to vertical stress (1-sinφ) as given by Lambe and Whitman, 1969, and Nc' and Nq' are bearing capacity factors depending on the properties of φ.

The use of the above two models has demonstrated that with knowledge of the critical aspect ratio for a particular tine in a given soil condition, useful predictions can be made of the horizontal and vertical force components acting on tines of any width by converting the critical depth function in the very narrow tine failure model into an aspect ratio term. The fact that this model consists of two separate failure mechanisms is analogous to the two suggested failure mechanisms whereby the transition point is determined by the critical aspect ratio term. The resulting general equation in terms of aspect ratio after incorporating the crescent effect and the sliding resistance component can be expressed as:

$DA = \gamma w^3 N_\gamma A_o^2 \sin(\alpha+\delta) + \gamma w^3 N_\gamma A_o^3 [m-1/3(m-1)]\sin(\alpha+\delta) + cw^2 N_a A_o \sin(\alpha+\delta)$

$+ cw^2 N_a A_o^2 \sin(\alpha+\delta)[m-1/3(m-1)] + c_a w A_o \cot\alpha + cw^2 m A_o^2 \sin(\alpha+\delta)$

$+ cw^2 Nc'(A-A_o)\sin(\alpha+\delta) + cw^2(A-A_o)\cos\alpha/\cos 45° + 0.5\gamma w^3 K_o Nq' (A^2-A_o^2) \sin(\alpha+\delta).$

The critical aspect ratio can be determined after differentiation of the general equation with respect to critical aspect ratio and equating to zero. The resulting function is in the form of a quadratic where the critical aspect ratio is in the positive root of the following equation

$A_o = [-b \pm)\sqrt{(b^2-4ac')}] / 2a$

where $a = 3\gamma w^3 N_\gamma [m-1/3(m-1)]\sin(\alpha+\delta)$

$b = w^2 \sin(\alpha+\delta)[2\gamma w N_\gamma + 2cN_a\{m-1/3(m-1)\} + 2mc - \gamma w K_o Nq']$

$c' = w2[cN_a \sin(\alpha+\delta) + wc_a \cot\alpha - cNc'\sin(\alpha+\delta) - c\cos\alpha/\cos 45°]$

To estimate the forces acting on tines, information on tine geometry, soil parameters and the rupture distance ratio is required. The above mathematical model was validated using data from soil tank force measurements. Accuracy of predictions vary with tine rake angles and soil moisture conditions. Beyond 50 mm wide tine, the predicted values using 45° rake angle were slightly lower whilst for the 90° rake angle, the predicted values were slightly higher. In general the shape and order of magnitude of the predicted draught curves are in close agreement with the experimental data (Desa Ahmad, 2002). As for the combined disc and rotary blade implement, mass moment of inertia approach was used to develop the energy prediction model (Desa Ahmad and Amran, 2004).The geometric parameters on disc forces and the force prediction for soil engaging discs considered in the model have been well discussed by Gill et al., 1978 and Godwin et al., 1987 respectively. The energy measured for a combination of disc plough and rotary blade was calculated using the following equations:

$$E_d = F_x \times S; \quad E_r = 2\pi \times (n/60) \times T \quad \text{and} \quad E = E_d + E_r$$

where, E_d = energy for cutting soil by disc plough, watt
F_x = draught force, N
S = forward speed, m/s
E_r = energy for cutting soil by rotary blade, watt
T = required torque of rotary blade, N-m
n = rotational speed of rotary blade, rpm
E = total energy, watt

The equations which were developed based on an understanding of the interaction between clay soil, disc and the rotary blade parameters were computed using the Math CAD PLUS 6.0 software.

The validity of the theoretical model at various forward and rotor speeds was verified via experiments conducted in an indoor soil tank. For a 40° disc angle, 0° tilt angle and 25 cm cutting width and a rotor speed of 200 rpm, the total energy increased with increasing forward speed. The measured values vary between -0.6% to + 3.3% compared to values predicted as shown in Figure 15. At a higher rotor speed of 400 rpm, the range of variation between measured and predicted values were -1.4% to + 2.5%.

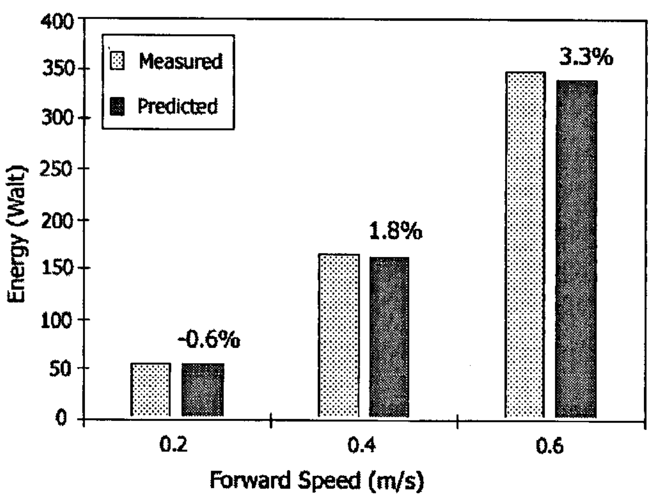


Figure 15 Comparison of measured and predicted values at a rotor speed of 200 RPM.

CONCLUSIONS

Performance data from various tractors and implements are essential for farm machinery management and manufacturers alike. Proper selection of tractors and implements for a particular farm situation can be determined from these performance parameters. This data can also be used to evaluate various farm machinery systems to determine the relative merits of each system. As field machines contribute a major portion of the total cost of crop production systems, proper selection and matching of farm machinery is essential to significantly reduce the cost of ownership and operation of farm machinery. For efficient equipment design and selection for any cropping system, precise knowledge of necessary soil conditions and of the transformations needed to achieve them is important. For implement design, it is convenient to define the required soil manipulations based on cultivation operations needed to change the existing soil state to the desired soil state. Implements must produce desired results under prevailing soil and moisture conditions, require minimum power and draught for maximum soil disturbance and match available power units and field sizes. For dryland cultivation, where moisture content may be close to plastic limit or lower, draught requirement increases with decreasing moisture content. Forward inclined tined cultivators or disc ploughs are suitable for loosening as their unit draught force is low.

In the case of wetland cultivation, land can be prepared under two conditions. In situations where the soil needs loosening before puddling, brittle failure is required. This is almost impossible to achieve with tines of whatever shape when the soil is in a plastic condition. Any such operation, therefore, needs to be conducted at lower moisture content and any clods formed should be reduced in size to enable rapid water uptake on wetting. Soil clods formed need to be puddled to the appropriate depth, giving a compact low permeability layer at its base that minimizes percolation and supports field traffic besides the need for mixing and incorporation of organic matter, compaction of pan by smearing and hydraulic sealing without increasing pan depth. The process of mixing soil with water is normally achieved by dispersing soil and breaking any clods further to enable rapid water uptake. Forward inclined tines help bring soil upwards but are not efficient tools for breaking clods and tend to move trash to the soil surface, though their unit draught force is low. Backward raked tines are good clod breakers but require higher draught force. The vertical tine provides the optimum shape to churn soil without incurring greater loss in draught force. This explains the popularity of vertical tines in the traditional comb harrow commonly used in many rice growing countries. The concept of tines with adjustable inclination angles appears to be a beneficial proposition especially for resource poor farmers. Tine inclination can be adjusted during the various stages of puddling.

In terms of energy usage, soil mixing with a single tine is not viable since it requires numerous passes. Multiple tine systems with closer spaced staggered tines would bring more soil to the surface as compared to wider spacings and are hence more efficient. However, unlike these combinations on dry soil, the leading tines do not reduce the draught on the rear tine. With backward raked tines, more soil would be moved sideways, generating greater soil water mixing as water trapped in the slots is further squeezed by the trailing tines. A system combining leading but forward raked tines with trailing but backward raked tines staggered and closely spaced would increase the efficiency of soil mixing with reduced number of passes.

In situations where the soil is very wet or submerged, it has little strength and is easily disintegrated and dispersed when loaded by almost any implement. Implements that readily penetrate the puddle layer, carry organic material downward and compact and smear at depth are backward inclined narrow tines, disc and presses which perform well but need large force. Powered rotary cultivators are also effective and have fewer draught problems. In cases where water is limited, the puddling process could be improved by increasing the input of mechanical energy. Additional water is needed only to overcome the scouring problem, if any. Forward inclined tines increase the risk of excessive penetration and incorporate organic matter poorly. Heavier implements require accurate depth control and should be used in combination with crumbler or paddle roll implements. With multiple tine systems, closer spacing of backward raked tines would help further mixing, smearing and burying of the organic material beneath the puddle layer.

The optimum farm power and machinery complement is achieved through a combination of the maximum tractor power demand for a single operation, the tractor fleet size for simultaneous operations and the tractor power mix to accommodate varying power requirements of different machines. For the future, it is recommended that suitable indices to characterize puddle soils that favour plant growth be developed and ways to achieve them using various implements be determined. The development of hardpan depth, bearing and shearing strength as well as their effects on machine mobility should be studied and last but not least is the development of light and high clearance tractors with best power to weight ratio as the prime movers for our rice fields.

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BIOGRAPHY

Professor Ir. Dr. Desa Ahmad was born in Perak where he also received his primary education. He then moved to Sekolah Dato' Abdul Razak, Tanjung Malim, Perak and Seremban, Negeri Sembilan for his secondary education. In 1973 he was awarded a MARA Scholarship to further his studies in England, UK.

Professor Ir. Dr. Desa Ahmad began his career as a lecturer at the Department of Biological and Agricultural Engineering, Universiti Putra Malaysia (UPM) in 1978 after graduating with B. Sc degree (Hons) in Agricultural Engineering from University of Newcastle-Upon-Tyne, England. He later obtained his M. Sc and Ph. D degrees in the same discipline from Cranfield University, England in 1980 and 1990 respectively. Since joining UPM, he has taught various courses related to Agricultural Engineering at Diploma, Undergraduate and Postgraduate Levels. He has also supervised and co-supervised over 100 undergraduates and 40 postgraduate students (21 of whom were foreign students). In 1993 he was promoted to Associate Professor and in 2002 to the status of Professor.

In terms of research, Professor Ir Dr. Desa Ahmad has wide interests in oil palm, paddy, cocoa, sweet potato, groundnut mechanisation and tillage of wet soil. He has been involved in at least 10 consultancy and design projects which include the setting up of 10 Farm Mechanisation Centres funded by the Asian Development Bank and in the the design of agricultural machinery for plantation crops. His current research interests are mainly on mechanisation of sweet potato and kenaf production, development of a paddy seeding machine for underdeveloped countries and controlled environments. He has won 3 medals (gold, silver and bronze) for collaborative research findings exhibited in UPM and

2 silver medals at exhibitions held in Kuala Lumpur and Germany respectively.

In his over 30 years of working, Professor Ir Dr Desa Ahmad has produced over 200 publications which include 10 books, 3 theses and 10 Consultancy Reports funded by the Asian Development Bank. He has also authored and co-authored at least 90 peer-reviewed publications in journals and proceedings published internationally and nationally among which are the Journal of Terramechanics, American Journal of Applied Science, International Journal of Heavy Vehicle Systems, Soil and Tillage Research, International Agricultural Engineering Journal, Agricultural Mechanisation in Asia, Africa and Latin America (AMA, Japan), Journal of Oil Palm Research, Journal of Paddy and Water Management, Journal of Environmental Management, International Journal of Vehicle Design, Journal of Automobile Engineering and PERTANIKA Journal of Science and Technology. Out of the 180 international and national workshops, seminars and conferences he has attended, including those held in Vietnam, Indonesia, China, Taiwan, Korea, Sri Lanka, Thailand, Europe and Australia, he has presented around 72 technical papers.

Professor Ir Dr Desa Ahmad is a Corporate Member of the Institution of Engineers, Malaysia and is registered as a Profesional Engineer in Agricultural Engineering with the Board of Engineers, Malaysia. He is also a member of various professional organisations including the Association of Asian Agricultural Engineers, Malaysian Society of Agricultural Engineers, American Society of Agricultural and Biological Engineers and Malaysian Society of Soil Science. He is also a regular reviewer for articles to be published in MARDI , MPOB, Academy of Science and CIGR research journals. Currently he is one of the editors for the

Malaysian Journal of Soil Science and the PERTANIKA Journal of Science and Technology.

Professor Ir. Dr Desa Ahmad has 18 years of management experience and is currently Head of Department of Biological and Agricultural Engineering. He was the longest serving Deputy Dean for Academic and Student Affairs at the Faculty of Engineering (from 1994 to 2003) and was the Chairman for various committees within the Faculty. He is now an active member of various committees at the University and National Levels such as the National Advisory Committee member on Oil Palm Mechanisation and a sub-committee member on Human Resources Development for Palm Oil Based Products (Post Industrial Master Plan). He was also appointed as the Management Representative for the implementation of MS ISO 9001. The Faculty was endorsed by SIRIM on 28 August 2001 as complying to the MS ISO 9001 without any Non Conformance Record. He was an International Advisory Member for the Soil Dynamics Conference, Australia, Advisor on Agricultural Design Project, Manchester Polytechnic, England, External Examiner and Assessor for the Sinaut Training Institute, Brunei Darussalam and he has also conducted professional courses for Myanmar Agricultural Officers. Currently he is one of the auditors for mechanical engineering laboratory equipment appointed by the Ministry of Higher Education and an appointed panel member of the Malaysian Qualifying Agency (MQA)

In 1992, Professor Ir Dr. Desa Ahmad was the recipient of the FFTC/ASPAC Award which fully paid his expenditure to participate in the Farm Mechanisation Workshop in Taiwan. In 1994 he was fully sponsored by the Commonwealth Council of Engineers to present a country report on the impact of agricultural engineering on the environment and sustainable development at an International Conference on Environmental Impact Assessment in Sri Lanka. In

1996, he received the award for inspiration from the Engineering Faculty Management and in 1999 he received the SETIAPUTRA award from UPM. Since year 2000 he has received the award for service excellence from University Putra Malaysia. Further, in 2002 he was the recipient of the 21st Century Award for Achievement in Agricultural Engineering from the International Biographical Centre, Cambridge, England.

On 1st June, 2005 Professor Ir. Dr. Desa Ahmad was appointed as the Director of the Centre for Food and Agricultural Mechanisation and Automation by the Vice-Chancellor of UPM. In recognition of all his contributions, Professor Ir. Dr Desa Ahmad was conferred the Royal Award Darjah Paduka Cura Si Manja Kini (P.C.M) by His Royal Highness Paduka Seri Sultan of Perak, Sultan Azlan Shah on 6th May, 2008.

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